4

Radionavigation System Research, Engineering and Development Summary

4.1 Overview

This section describes Federal Government research, engineering and development activities relating to the Federally provided radionavigation systems and their worldwide use by the U.S. Armed Forces and the civilian community. It is organized in two segments: (1) civil R,E&D efforts to be conducted mainly by DOT and to a lesser extent by NASA and NOAA, and (2) DOD research and engineering (R&E) for military uses.

The DOT R,E&D activities consist of parallel efforts to develop current and future navigation systems to improve existing operations or to identify systems which can replace or supplement those now being used in civil air, land or marine applications. The parallel efforts are described in two major sections, one covering GPS and the other covering all other existing systems (such as VOR, Omega, and Loran-C) now in use or being considered by DOT to meet new or emerging navigation requirements.

Although the DOT R,E&D activities for GPS will proceed in much the same manner as those for other systems, GPS has been identified separately because of its broad multimodal civil and military applications and the consequent need for close cooperation between Federal agencies in its evaluation. Such a cooperative effort will minimize duplication of effort and promote maximum productivity from the limited resources available for civil research. DOT's participation in the evaluation and development of GPS ensures that benefits can be derived from DOD's advances in systems technology.

From the point of view of DOT, the analysis of performance requirements of civil navigation systems involves a variety of complex factors before it can be concluded that a specific system satisfies the principal objective to ensure safety and economy of transportation. These factors involve an evaluation of the overall performance and economics of the system in relation to technical and operational considerations, including vehicle size and maneuverability, vehicle traffic patterns, user skills and workload, the processing and display of navigation information, and environmental restrictions (e.g., terrain hazards and other obstructions). For this reason, a DOT comparison of one navigation system to another requires more than just a simple evaluation of accuracy and equipment performance characteristics. As a first step in the comparison of system capabilities, ten parameters, discussed in Appendix A, can be identified and are listed below:

- Signal Characteristics
- Accuracy
- Availability
- Coverage
- Reliability
- Fix Rate
- Fix Dimensions
- System Capacity
- Ambiguity
- Integrity

User equipment costs are a major consideration if universal civil participation is to be achieved. DOT R,E&D activities may involve evaluations and simulations of low-cost receiver designs, evaluation of future technologies, and determination of future requirements for the certification of equipment.

In contrast to DOT, the DOD R&E activities mainly address evaluations by Armed Forces user groups which are identified by military mission requirements and national security considerations. For this reason, DOD R&E is defined to include all activities before the final acquisition of a navigation system in accordance with detailed system specifications. The DOD view of Transit, Loran-C, TACAN, VOR, ILS, and Omega is that these systems are already developed and, therefore, do not require R&E.

Although there are some similarities between the DOD and DOT analyses of the system parameters, DOD military missions place much greater emphasis on security and anti-jam capabilities. Such factors as anti-jam capabilities, updating of inertial navigation systems, input sensors for weapon delivery, portability, and reliable operation under extreme environmental or combat conditions become very important in establishing the costs of the navigation equipment.

Concurrent with the Federal R,E&D programs, the major cost issues will be evaluated. These evaluations and R,E&D programs will be used to support joint positions related to system mix, phase-in and phase-out, and transition strategies for common-use systems.

The relationship between DOT and DOD R,E&D programs is based on a continuing interchange of operational and technical information on radionavigation systems. DOD R,E&D will be coordinated with DOT R,E&D under the following guidelines:

- DOT will evaluate the costs of all radionavigation systems which meet identified civil user requirements.
- DOT will provide DOD with the most current information on civil user requirements which may have a significant impact on DOD-operated radionavigation systems.
- Consistent with existing DOD policy, DOD will provide information to DOT on GPS receiver designs that may be applicable to civil receiver development.
- DOT will conduct studies of GPS performance capabilities of receivers in order to provide an assessment of their applicability to the civil sector.
- DOD/DOT will not constrain the use of SPS-based differential GPS service as long as applicable U.S. statutes and international agreements are adhered to.
- DOT will cooperate in the development of differential correction reference stations for the best possible differential/integrity network.
- DOT has investigated and is continuing to investigate the use of both GPS and GLONASS signals by the same receiver.

The specific civil R,E&D activities are outlined below in two segments: 1) GPS R,E&D, and 2) R,E&D for other navigation systems including VOR, TACAN, DME, Omega, Loran-C, ILS, and MLS. These activities have been coordinated to achieve efficient use of the limited funds available for R,E&D and to avoid duplication of effort. R,E&D tasks for the individual DOT agencies (FAA, USCG, MARAD, etc.) and related tasks by NASA are addressed and schedules have been specified so that the results of the efforts will be of maximum usefulness to all participants in the program. R,E&D schedules and activities for the FAA, the USCG, and RSPA have been identified respectively under civil aviation, land and marine activities in this document.

4.2 DOT GPS R,E&D

DOT R,E&D activities for GPS have been conducted primarily by the USCG, the FAA, the FHWA, and RSPA. Efforts initially were directed primarily toward determining the capability of GPS to meet civil user needs in the air, land and marine transportation communities. Subsequently, as it became apparent that the GPS capability to be provided to the civil community would not meet all user requirements, efforts have focused on ways of enhancing the system to meet these civil needs. The major DOT air, land and marine R,E&D activities for GPS are described as follows:

A. DOT, with DOD and NOAA as co-sponsors, tasked the Institute for Telecommunications Sciences, with support from the U.S. Army Corps of Engineers (ACOE) Topographic Engineering Center and the DOT Volpe Center, to evaluate the capabilities of augmented GPS technologies for meeting the requirements of aviation, land and marine users. As part of this task, the current requirements of these users were examined, and the augmented GPS options were evaluated to determine if they can satisfy user requirements. The study developed recommendations for an integrated GPS system or systems to meet the needs and requirements of Federal Government users. These recommendations are currently under evaluation.

B. USCG activities focus on verifying and improving the performance of GPS for maritime navigation. There is particular emphasis upon the harbor/harbor approach phase of marine navigation, where augmentation of visual piloting and positioning of other aids to navigation using radio aids to navigation is needed. Major efforts are to:

   - Verify the differential GPS concept and techniques developed by the RTCM/SC-104 on differential GPS.

   - Initiate action to publish a standard for a marine differential GPS system after the RTCM/SC-104 concepts and techniques have been verified.

C. The FAA's basic R,E&D activities for the introduction of GPS into the NAS are currently focused on the GPS WAAS to satisfy accuracy, coverage, reliability, and integrity for all phases of flight down to Category I precision approach. Additional R,E&D activities to exploit the full capabilities of GPS for civil aviation are continuing.

D. RSPA will continue to review the results of work in the design of low-cost GPS receivers and field tests of GPS performance conducted by other organizations.

E. The ITS field operational test ADVANCE (Advanced Driver and Vehicle Advisory Navigation Concept) in Chicago has plans to use and test DGPS technology for its in-vehicle route guidance and navigation system.

4.2.1 Civil Aviation

The FAA, through its GPS R,E&D program, is developing the requirements for use of GPS in the national airspace to meet RNP. This includes refining the appropriate standards for GPS airborne receivers and developing the air traffic control methodology for handling GPS area navigation aircraft operation in an environment with non-GPS equipped aircraft. The FAA has certified GPS as a supplemental means of navigation. The use of GPS as a primary means of navigation depends on the successful development, deployment, and operation of the WAAS, as well as the development of appropriate standards, operating procedures, and avionics. The objective of the FAA is to support the integration of GPS and DGPS into the NAS in an evolutionary manner. The evolving WAAS will be a key component of the NAS precision approach and landing architecture. The WAAS is projected to meet all requirements for Category I precision approach. Additional augmentation will be required to support Category II and III operations. Other augmentation and auxiliary/hybrid sensors may also be employed, and are currently being examined. There is close cooperation between FAA, DOD, and industry in these efforts. A Memorandum of Agreement between FAA and DOD to implement GPS for civil aviation was signed on May 15, 1992.

The FAA is actively supporting the activities of the ICAO and RTCA, Inc. in the definition of the Global Navigation Satellite System (GNSS) and associated implementation planning guidelines. The GNSS is intended to be a worldwide position, velocity and time determination system. GNSS will include one or more satellite constellations, end-user receiver equipment, a system integrity monitoring function, and ground-based services augmented as necessary to support the RNP for specific phases of flight. GPS will be the primary satellite constellation used for navigation during early GNSS implementation. The FAA's activities in support of ICAO and RTCA will ensure that satellite navigation capabilities are implemented in a timely and evolutionary manner on a global basis.

The FAA has examined a variety of implementation strategies for incorporating GPS-based navigation into the NAS. Consequently, the FAA is implementing satellite navigation through an industry/government partnership that achieves user benefits in all phases of aviation operations.

The FAA is actively pursuing technology related to GPS augmentation in order to achieve a new primary means of navigation capability. While several methods are being analyzed and developed, WAAS is fully endorsed and is being developed by the FAA. This satellite-based augmentation concept has been operationally demonstrated for use in all phases of flight with a system prototype. Production of the system is scheduled for commissioning in 1997.

A. FAA Research, Engineering and Development Accomplishments To Date

- The FAA has allowed the use of GPS positioning data as input to multi-sensor navigation systems for selected IFR phases of flight using existing criteria for operating minima, flight inspection, obstacle clearance, and ATC separation standards.

- The FAA has approved the use of GPS as a supplemental civil aviation navigation system and as a primary system for oceanic and specified remote areas.

- The FAA has published a GPS National Aviation Standard.

- The FAA participated in the development of a Minimum Aviation System Performance Standard (MASPS) for GPS Special Use Category I precision approaches and has published an Order describing its use on private grounds.

- The FAA has initiated an “overlay” project to quickly certify about 5,000 GPS nonprecision approaches.

- The FAA has supported the satellite navigation activities of the Air Transport Association, the National Business Aircraft Association, and the Aircraft Owners and Pilots Association user groups to develop customer capabilities.

- The FAA has developed a U.S./GPS and Commonwealth of Independent States (C.I.S.)/GLONASS common receiver test set to collect data and support developing avionics MOPS.

- The FAA has established cooperative research agreements with aviation community organizations such as NASA Ames, Ohio University, Stanford University, Honeywell, and Alaska Airlines to investigate the use of GPS for precision approaches

- The FAA has established international cooperation for developing the GNSS through the ICAO Future Air Navigation System (FANS) IV research and development working group.

- The FAA has participated in the development of the WAAS MOPS.

B. Planned FAA Research, Engineering and Development GPS Activities

For primary means of navigation, the FAA is pursuing the development of the WAAS to enhance the availability and integrity of GPS. IOC is scheduled for 1997. The FAA is also researching the development, deployment, and certification of the WAAS as a public-use system for Category I precision approaches. There is a continuing certification standards R,E&D effort to support Category I.

Emphasis is placed on the GPS-based navigational benefits and associated activities for the oceanic, domestic en route, nonprecision approach, and Category I precision approach phases of flight. This reflects that these benefits are near-term, while the capability of GPS to provide navigation guidance for Category II and III precision approaches and airfield surface navigation remains relatively long-term and requires further research.

Activities are ongoing to study the potential impact of radio frequency interference (RFI) and jamming and spoofing on navigation and landing operations and to develop suitable mitigation techniques for the avionics, ground-based receivers, and overall augmentation systems as appropriate. Initial focus is on phases of flight down to CAT I, and will be expanded to include CAT II/III precision approach performance standards.

Long-term R,E&D is being conducted to determine the feasibility of augmenting GPS for conducting Category II and III precision approaches. This activity includes multiple FAA funded demonstrations by a number of contractors, as well as (potentially) non-government funded demonstrations and studies by industry and academia worldwide.

Other activities are to:

- Develop RNP parameters for all phases of flight from oceanic en route to CAT III precision approach, and surface navigation. Early outputs from this task are needed to support rule-making for CAT I operations as well as en route operations based on GPS augmented with WAAS. RNP for CAT II/III are deferred somewhat but are required by mid to late 1995 to support decision-making regarding the far-term NAS precision approach and landing (NASPALS) architecture.

- Develop CAT II/III standards. This activity contains multiple elements such as development of TSOs, FAA Orders and ACs, and configuration management updates of NAS documentation.

- Track the RF carrier phase during high dynamic movements to obtain sub-meter navigation accuracies.

- Obtain real-time (1 second or less) integrity.

- Provide continuity of service which can meet requirements for landing and rollout under very low visibility weather conditions.

Table 4-1 shows the FAA schedule for the development of GPS performance standards for civil avionics.

4.2.2 Civil Marine

The R,E&D activities of the USCG related to marine uses of GPS have historically been: (1) user field tests for comparative assessment of GPS versus alternative aids to navigation; (2) assessment of SPS performance potential; and (3) assessment of using differential GPS for various applications including harbor/harbor approach

Table 4-1. Development of GPS Performance Standards for Civil Avionics

Phase of Flight	CALENDAR YEARS								
	1992	1993	1994	1995	1996	1997	1998	1999	2000
GPS as Input to Multi-Sensor Navigation									
En Route Oceanic	Complete								
En Route Domestic	Complete								
Terminal	Complete								
Nonprecision Approach	Complete								
GPS Supplemental Navigation									
En Route Oceanic		Complete							
En Route Domestic		Complete							
Terminal		Complete							
Nonprecision		Complete							
GPS Augmented for RNP									
En Route Oceanic (FMS/IRS/ADC)									
En Route Oceanic									
En Route Domestic									
Terminal									
Nonprecision Approach									
Precision Approach Cat I									
Precision Approach Cat II & III (Determine Feasibility)									

navigation. The purpose of the marine program is to acquire a sufficient base of knowledge to determine those missions of the marine fleet for which the GPS system can satisfy the navigation performance requirements. Issues important to the use of GPS for marine navigation include:

- Accuracy: Non-augmented GPS cannot provide the accuracies needed by marine users in some applications, including commercial fishing, where repeatable accuracies of 50 meters using Loran-C are commonplace; the offshore industry, which requires 1 meter accuracy; harbor/harbor approach, which requires 8-20 meter accuracy; and inland waterway navigation, the requirements of which are undefined, but will surely be more restrictive than that of harbor navigation.

- Technical and Economic Factors: Technology, and a rapidly-developing satellite constellation, have driven the costs of GPS equipment dramatically lower than that predicted two years ago. This trend should also occur over the next two years with DGPS receivers. Government activity in this area will be limited to participation with industry in the development of performance standards and functional requirements for receivers to support carriage requirements for vessels.

- Use with ECDIS: DGPS receivers are most effective when used with some form of automated chart display. Its extreme accuracy (small fractions of a minute of latitude and longitude) is difficult to plot manually, and its capability of outputting position data at intervals of one second or less is far beyond the human ability to plot the information in real time. Research into the integration of highly accurate position sensors such as DGPS is ongoing.

The USCG has completed its proof-of-concept for DGPS use in harbor/harbor approach navigation. The system greatly exceeded the required levels of performance. Future work will focus on jamming and spoofing of the GPS signal. The USCG is working with the RTCM to develop correction messages for geostationary satellites that will provide ranging signals. Working with the RTCM, the USCG has participated in developing a message to broadcast ionospheric measurements which will be thoroughly characterized through field testing. This message, the Type 15, will extend the high accuracy achieved in the vicinity of the reference station out to several hundred miles.

4.2.3 Civil Land

Land radionavigation users, unlike air and marine users, do not come under the legislative jurisdiction of any agency. For this reason, RSPA has attempted to monitor land user activities and identify R,E&D activities applicable to user needs. Limited RSPA R,E&D performed in past years through the Volpe Center indicated some limitations to the serviceability of GPS to land users in certain urban areas. RSPA will monitor technology developments in the private sector and the results of other government sponsored R,E&D activity in the following areas:

- Land user equipment availability and cost.
- GPS land performance.
- Differential GPS technology development and system performance.
- Land navigation and radiolocation applications.
- Commercial system development status, performance and applications.
- Possible Government use of commercial navigation, radiolocation, and communications systems for air, land and marine users.

RSPA, FHWA, and NHTSA will also participate in joint industry, user, and government groups developing standards for using radionavigation equipment displays and databases in land vehicles. RSPA, as the DOT focal point for hazardous materials transportation, will also study GPS tracking technologies.

Several departments and agencies of the Federal Government are sponsoring R,E&D activities that use existing radionavigation systems for various land uses. Federal and state governments and private industry are conducting research, as part of the ITS program, to assess the feasibility of using in-vehicle highway navigation and automatic vehicle location to satisfy the needs of ITS user services. Table 4-2 lists operational tests using GPS that are wholly or partially funded by FHWA. These operational tests are also shown in Figure 4-1. A complete listing of R&D studies and operational tests wholly or partially funded by FHWA, FTA and NHTSA can be found in DOT's *Intelligent Vehicle Highway Systems Projects*, *March 1994*. These tests are focused on the development of ITS user services that will achieve improvements in safety, mobility, and productivity, and reduce harmful environmental impacts, particularly those caused by traffic congestion. The following paragraphs describe some of these tests.

ADVANCE is a cooperative effort to evaluate the performance of the first large-scale, dynamic route guidance system in the United States. Participants include the Illinois DOT, Motorola, Inc., the Illinois Universities Transportation Research Consortium, and the FHWA. Up to 5,000 private and commercial vehicles in the northwestern suburbs of Chicago will be equipped with in-vehicle navigation and route guidance systems. Vehicles will serve as probes, providing real-time traffic information. This information will then be transmitted to the equipped vehicles and used to develop a preferred route. The routing information will then be presented to the driver in the form of dynamic routing instructions.

Table 4-2. Examples of ITS Operational Tests Using GPS

FHWA Tests funded prior to FY 93 using GPS

Test Name			
ADVANCE (Chicago)	GPS	Geolocation for map-matching	1994-7
TRAVTEK (Orlando)	GPS	Geolocation for map-matching	1992

FY 93 Operational Tests using GPS

Test Name			
Colorado Advanced Public Transportation	GPS	Automated Vehicle Location for mass transit scheduling	1995
Iowa, Minnesota, Wisconsin Border Crossings	GPS	Mileage determination	1994-5
New York City Mass Transit Authority Travel Information Test	GPS	Automated Vehicle Location for mass transit scheduling	1994-5

FY 94 Operational Tests using GPS

Test Name			
Atlanta En Route Traveler Advisory	DGPS	Geolocation for radio tuning information	1996
Idaho Motor Carrier Safety Assistance Program Out-of-Service Verification	GPS	Automated Vehicle Location	1995-6
Seattle Wide Area Communications System/Bellevue Smart Traveler	GPS	Geolocation for map-matching	1995-6
Project NORTHSTAR, New York/Connecticut/ New Jersey Metro Area	GPS/DGPS	Geolocation for mayday	1995-6
Advanced Rural Transportation Information and Coordination (Minnesota)	GPS	Geolocation for routing and mayday	1995-6
Colorado Mayday	GPS	Geolocation for mayday	1995

All dates are by the scheduled time of test.

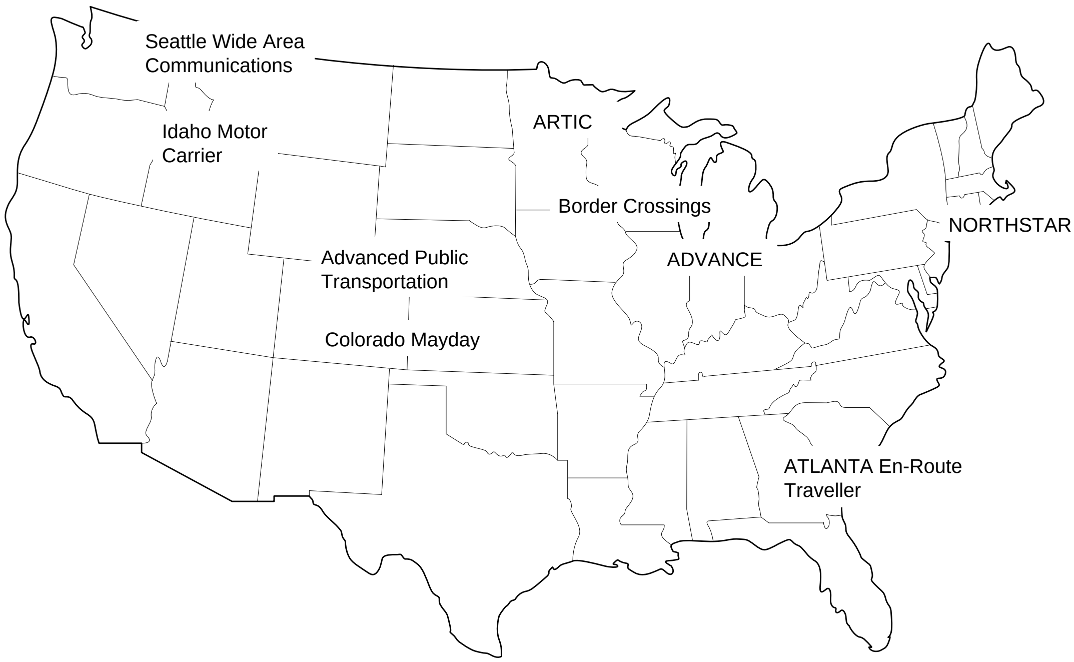

Figure 4-1. Selected ITS Operational Tests Using Radionavigation

The Onboard Automated Mileage Test in Iowa, Minnesota, and Wisconsin is a three state project that will test and evaluate the effectiveness of using GPS and first-generation onboard computers to record the miles driven within a state for fuel tax allocation purposes in a manner acceptable to state auditors. The system will automatically record mileage by specific roadway as well as state border crossings using GPS and vehicle location technology with a map-matching algorithm.

The Baltimore Mass Transit Administration (MTA) is implementing an automatic vehicle location system that will provide bus status information to the public while simultaneously improving bus schedule adherence and labor productivity. A prototype system involving 50 buses is being tested with Loran-C receivers and 800-MHz radios. The buses' location is determined by the receiver and the information is transmitted to central dispatch center. Off-schedule buses are identified so corrective action can be taken. The system will be expanded to include all 900 Baltimore transit buses and GPS inputs will replace Loran-C for vehicle location.

Dallas Area Rapid Transit (DART) has installed an Integrated Radio System that includes automatic vehicle location. When completely installed in mid-1994, 8,323 transit buses, 200 mobility impaired vans and 142 supervisory and support vehicles will be equipped. GPS will generate vehicle location information.

The Colorado Mayday System operational test calls for the installation of in-vehicle devices which are capable of capturing a snapshot of available GPS location data, and other vehicle related emergency information, and a communications system primarily based on cellular telephones and specialized mobile radio units. A control center will be established to receive and process emergency assistance requests from the in-vehicle units and determine vehicle location from the GPS data that was included in the emergency assistance request. The control center will determine the nature of the request and forward it to the appropriate response agency for action. The motorist will then be notified by the control center on the actions taken and the expected response time. The in-vehicle unit will be capable of automatically activating the emergency assistance request under some conditions where the driver may be incapacitated. In addition, there will be a button box that will allow the driver to initiate a specialized call for assistance ranging from vehicle service or repair to medical emergencies. The Denver, Colorado Rapid Transit District (RTD) Passenger Information Display System will use data gathered from the AVL system, currently being installed on all RTD buses, to provide information to video monitors at selected locations regarding estimated bus departures for waiting bus passengers.

A number of services are evolving that use GPS-based AVL systems. In mass transit systems, they are being proposed for use in computer aided dispatch, traffic signal pre-emption and bus stop annunciation. Within the trucking industry, companies have equipped vehicles with GPS receivers to aid in fleet management. Knowing the location of every vehicle across the nation at any instant in time will allow more efficient planning and operations. Urgent pick-up and delivery services to customers will be possible and rapid and optimal rescheduling of each vehicle’s itinerary is expected to result in improved productivity.

4.3 DOT R,E&D for Other Navigation Systems

The main purposes of DOT navigation systems R,E&D are to improve reliability and service, decrease costs, and satisfy new requirements. The major DOT R,E&D for systems other than GPS is outlined in the context of air, land and marine areas of operation.

A. Air

The FAA will continue to modernize VOR/DME to reduce operation and maintenance costs and to improve the performance of these aids. The FAA will also continue to monitor the performance of Omega on oceanic air routes and the use of Omega and Loran-C as supplements to VOR/DME.

B. Marine

The DOT marine R,E&D for existing systems is composed of several programs. USCG R,E&D projects focus on system enhancements and techniques for improving navigation safety in the harbor/harbor approach phase of marine navigation, principally involving shipboard displays as well as enhanced VTS equipment designs to prevent vessel casualties, loss of life, or pollution of the marine environment. A project is also under way to evaluate the requirements for harbor/harbor approach navigation system performance.

MARAD, in cooperative research with the private sector and the USCG, has developed a computerized decision support system for safe navigation which combines artificial intelligence technology, digital chart data bases, vessel maneuvering data, and precise positioning information to enhance piloting performance in the harbor/harbor approach and coastal phases of navigation. The system has been undergoing an operational evaluation aboard ship which should prove its contribution to safe navigation.

C. Land

As navigation benefits to land users become more apparent, and as receiver equipment costs decrease due to technology improvements and expanding user markets, adaptation of the existing navigation systems to serve a variety of land users will prove cost-effective. Typical applications include site registration for remote site location, highway records, land management, and resource exploration; AVM/AVL for truck fleets, railroad transportation management, buses, and police and emergency vehicles; driver information systems for highway vehicles; and navigation applications for highways and remote areas.

4.3.1 Civil Aviation

The aviation community has recognized that the existing ground-based navigation systems have reached their full potential. Consequently, the FAA’s R,E&D program will concentrate on the exploitation of satellite-based technologies, specifically GPS.

The R,E&D activities of the FAA are broadly directed toward improving navigation systems serving civil and military air users. The activities cover five phases of flight: (1) oceanic and domestic en route; (2) nonprecision approach; (3) remote areas; (4) vertical-flight IFR operations; and (5) precision approach and landing.

The FAA navigation program has three specific goals: (1) to provide information that will support FAA recommendations on the future mix of navigation aids; (2) to assist in the near-term integration of existing navigation aids into the NAS as supplements to VOR/DME; and (3) to provide information that will support the definition of long-term navigation opportunities.

Possibilities exist to develop receiver avionics which combine two radionavigation signals such as GPS/Loran-C, GPS/GLONASS, GPS/Omega, and GPS/VOR/DME, and thereby significantly improve user navigation performance. FAA, in cooperation with industry, is developing standards under which an individual system or combination of systems may be certified to meet RNP in an aircraft conducting IFR, en route, and terminal area operations, including nonprecision approach, in controlled U.S. airspace.

In the long term, communications, navigation, and surveillance (CNS) may be combined into an integrated communications and navigation system (ICNS) providing a seamless system for civil users. Low-altitude users, including VFR as well as IFR traffic, could be accommodated more easily in the NAS since one ICNS system would respond to the needs of all users.

ICNS services would extend ATC service to more airspace in support of flexible routes. This airspace includes extreme (low and high) altitudes, oceanic, offshore, remote, and urban environments.

Time-based navigation and ATC practices in the en route and terminal environment would involve issuing time-based clearances to certain aircraft which can navigate with sufficient precision to fly space-time profiles and arrive at points in space at specified times. Aircraft equipped with advanced flight navigation and management systems may be able to receive clearances directly from ground automation equipment, and follow such clearances automatically along trajectories of their choice, either to maximize fuel efficiency or to minimize time. This will also enhance the utilization efficiency of the NAS, allowing increased capacity without a proportional increase in infrastructure expenditures.

Automatic dependent surveillance (ADS) is defined as a function in which aircraft automatically transmit navigation data derived from onboard navigation systems via a datalink for use by air traffic control. Automatic dependent surveillance R,E&D will develop functions to permit tactical and strategic control of aircraft. Automated position report processing and analysis will result in nearly real-time monitoring of aircraft movement. Automatic flight plan deviation alerts and conflict probes will support reductions in separation minima and increased accommodation of user-preferred routes and trajectories. Graphic display of aircraft movement and automated processing of data messages, flight plans, and weather data will significantly improve the ability of the controller to interpret and respond to all situations without an increase in workload.

Oceanic En Route

Oceanic navigation is achieved through the use of Omega and inertial navigation systems. Limited accuracy and cumulative errors result in a lack of timely, accurate, and reliable aircraft position determination, reporting, and tracking. This forces large, safety-conscious spatial and temporal separation standards for aircraft flying trans-oceanic routes.

Domestic En Route

Domestic en route navigation is achieved through the use of VOR/DME, GPS, Loran-C, NDB, and TACAN. The current primary navigation system for the domestic en route structure relies on navigation between ground-based VORs.

Nonprecision Approach

No initiatives beyond the use of GPS are contemplated for this phase of flight at this time.

Remote Areas (including offshore)

Although VOR/DME coverage meets most civilian user requirements, there are areas, such as some mountainous regions and low-altitude airspace areas, where there is a requirement for air navigation service that VOR/DME does not presently provide. Alternatives being investigated to provide the required coverage include additional VOR/DME facilities, and supplementing the existing VOR/DME system with GPS or Loran-C. Currently, Omega/VLF, GPS, and Loran-C (in specific areas) are approved as a supplement to VOR/DME.

Vertical-Flight IFR Operations

GPS-based navigation offers new opportunities for vertical-flight aircraft to operate more efficiently in the NAS. As prime examples, significant benefits can be derived in the near term through virtually uninterrupted emergency medical services to hospitals and trauma centers in all weather operations, undelayed passenger carrying operations and optimized low-altitude air routes.

Emergency medical services have long recognized the importance of delivering prompt medical attention and expeditiously transporting patients to and between medical facilities. GPS-based navigation enhances this potential by enabling instrument approaches to every hospital with sufficient obstacle-free airspace. The FAA is investigating how best to maximize this new capability through reduced TERPS obstacle clearance areas, steeper glide slopes, and curved approaches for vertical-flight aircraft. The first stage of this testing focuses on nonprecision approaches. Tests of vertical-flight aircraft performance during nonprecision approaches are being conducted at four heliport sites. Data collection will focus on system-use accuracy and pilot workload over various combinations of glide slopes and curved approaches. Follow on testing will examine precision approach and en route navigation requirements. The results gained during these tests can also be applied to a wide variety of other vertical-flight aircraft missions.

Passenger-carrying operations using vertical-flight aircraft is one method of reducing congestion and delays at high activity airports and on highways. In terminal areas, however, this will work most efficiently if vertical-flight aircraft can operate independently of the regular fixed-wing traffic flow. The high accuracy of

GPS-based navigation together with the unique flight capabilities of vertical-flight aircraft can enable undelayed approaches. The FAA is examining methods to optimize these traffic patterns and approaches into high activity airports to eliminate delays regardless of the weather.

The vertical-flight community has identified the need to have low altitude IFR routes that are nearly direct and separate from high traffic fixed-wing routes. Flying IFR at low altitudes is also important in many areas of the United States, most notably the northeast United States, to avoid the frequent icing conditions. Due to the limitations of VOR, only one such IFR route had been feasible. GPS-based navigation can enable these types of routes to be developed wherever a need exists. The FAA has begun analyzing these requirements and the best methods to integrate this route structure into the NAS.

Precision Approach and Landing

Presently, the ILS ground-based system is the only system used to support CAT II/III operations. GPS without proper LADGPS augmentation cannot support CAT II/III operations. The FAA is currently funding research designed to investigate the feasibility and utility of various LAAS augmentations to support CAT II/III operations. Until the research is completed, CAT II/III requirements will be met by ILS. From a strategic planning perspective, several other CAT II/III future architectures are being considered.

Local-area DGPS systems, ILS, GLONASS and other navigation sources and sensors may play roles of varying significance in the far-term precision approach architecture.

4.3.2 Civil Marine

The USCG plans for improving marine navigation systems, which serve the civil maritime user, are described below. They cover the following phases of marine navigation: inland waterway, harbor/harbor approach, coastal, and ocean.

Inland Waterway and Harbor/Harbor Approach

No efforts are being expended by the USCG to develop any radionavigation systems for inland waterways. However, the USCG is anticipating expansion of DGPS through a joint effort with the ACOE to meet navigation requirements of certain inland waterways.

There is no existing Federally provided radionavigation system capable of meeting the 8 to 20 meter (2 drms) accuracy required for marine navigation in harbor/harbor approach areas. Loran-C can meet these requirements in a few selected areas. The USCG developed and demonstrated a differential Loran-C system that nearly met these accuracy requirements in many, but not all, major harbor areas. This effort has been terminated in favor of efforts involving DGPS.

USCG DGPS will be implemented to meet the marine navigation requirements of harbor/harbor approach. The system will use fixed GPS reference stations which will broadcast differential corrections over USCG radiobeacons. The system has potential application in marine and terrestrial navigation and survey operations. The system is based on differential message and data standards developed by a multidisciplinary committee under the sponsorship of the RTCM. A proof of concept differential system, including the radiobeacon data link and user equipment, was tested in 1990. It is being refined in preparation for deployment to the field.

Ship simulator studies were conducted to evaluate the minimum radionavigation sensor accuracy and display requirements for piloting in restricted waterways. These studies helped to provide a basis for establishing requirements for harbor/harbor approach navigation system performance.

Coastal

Loran-C and GPS meet the radionavigation requirements for the coastal phase of marine navigation. As it is implemented, DGPS will also be usable in much of this navigation phase. No R,E&D activities are ongoing or planned.

Oceanic

The primary system used for oceanic navigation is GPS. Omega will also be used by a declining user base until it is phased out. No R,E&D activities are ongoing or planned.

4.3.3 Civil Land

The Baltimore Mass Transit Administration is testing a prototype AVL system using Loran-C receivers. Bus location is determined by the receiver and the information is transmitted to a central dispatch center. Off-schedule buses are identified for corrective action. The system will be expanded to include all 900 Baltimore transit buses and GPS inputs will replace Loran-C for vehicle location.

4.4 GPS R&D Ongoing and Planned by NOAA

NOAA continues to perform GPS research and development for precise geodetic modeling and applications.

NOAA continues to improve the modeling for the determination of precision GPS orbits for precision applications such as precise determination of global tide gauges, precise determination of orthometric heights based on a combination of double-differenced GPS and a gravimetric geoid, and measurement of polar motion of the Earth.

NOAA's GPS geodetic program includes the formation of a geodetic network of Continuously Operated Reference Stations (CORS) whose geodetic positions are known and consistent at the few-centimeter level nationwide. NOAA continues to work closely with the USCG, the FAA, and other agencies to help develop standards for CORS activities, to provide geodetic control to CORS sites and other monuments, and to make arrangements for access to GPS measurements for widespread public use.

NOAA continues its commitment to GPS research and development, improved GPS orbits, and a geometric network which is accessible and precise both in the geometric sense (NAD83) and in the orthometric sense (NAVD88). One of NOAA's primary charters is to encourage all public and private users to reference their positioning and navigation results to the NOAA geodetic networks.

4.5 GPS R,E&D Planned by NASA

NASA is conducting R,E&D in a number if GPS application areas in the space, aeronautics, and terrestrial environments. These efforts include:

- ***Space Applications:*** The emphasis in the space applications R,E&D of GPS is primarily on development of off-the-shelf GPS receivers that can be installed in instrumented spacecraft. These receivers will be capable of providing onboard navigation products, providing GPS time signals for distribution to spacecraft systems and instruments, providing necessary data for post-pass processing in support of science data collection, and determining spacecraft attitude.

  Particular emphasis is being placed on research supporting the determination of attitude using spaceborne GPS receivers. NASA is working with industry to refine attitude determination techniques using GPS for both the Lewis and Clark small satellite program and for the International Space Station.

  NASA is also continuing to refine the post-pass processing techniques used to support precise analysis of scientific data requiring precise knowledge of spacecraft position at data collection time.

- ***Aeronautics Applications:*** GPS receivers aboard NASA aircraft are being used for both aeronautics research and in support of airborne scientific observations. There are numerous projects throughout NASA where GPS technology is being developed for these purposes. For example, in the aeronautics research area, GPS is being used in work being done at the Langley Research Center in wake vortex measurement systems in support of the terminal area productivity enhancement research. NASA is also conducting research using GPS for precise pointing of instruments from the Stratospheric Observatory For Infrared Astronomy (SOFIA) aircraft, use in the Airborne Synthetic Aperture Radar (AIRSAR) program in the production of Digital Elevation Models (DEMs) of the earth's surface, and for positioning of aircraft while taking annual thickness measurements of the Greenland ice sheet.

- ***Terrestrial Applications:*** NASA is sponsoring the continued development of the International GPS Service (IGS) for Geodynamics. Areas of research include continued enhancement of the software used to determine orbit ephemerides and techniques for improving measurement accuracy to the 1 mm level.